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Influences of Crumb Rubber Sizes on Hot Mix Asphalt Mixture

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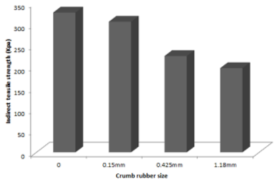
Graphical abstract



Abstract

Crumb rubbers (CRs) have been proposed as pavement components because they are waste materials. Previous studies have attempted to find alternative material in pavement construction that act as additives or property modifier. The current study presents a laboratory experiment using CR recycled from discarded vehicle tiresas additives in hot mix asphalt (HMA). CR was added using the dry process technique. Three rubber sizes were used with the following measurement: 0.15, 0.425, and 1.18mm. CR was added 2% of the weight of total aggregates. Bitumen80/100 penetration was used throughout the experiment. The effect of CR size on the mixture was investigated in terms of resilient modulus, indirect tensile strength (ITS), stability and dynamic creep. Experimental results revealed that the four engineering properties decreased when CR was added to HMA and when CR size was increased. However, the increasedCR size similarly increased the permanent deformation values. The data analysisshowed that 0.15mm CR is the most effective material for asphalt mixturebecause of the partial interaction between rubber particles and bitumen.

Keywords: Crumb rubber;resilient modulus;Indirect tensile strength;dynamic creep; dry process

■1.0 INTRODUCTION

The creation and accumulation of waste is an ongoing threat to the environment [1, 2]. Old tires in particular do not decompose and are continuing environmental problem. Unfortunately, tires are designed to be hard and are characterized by their chemical, biological, and physical resistance, which make them difficult to dispose. Stockpiled tires present additional challenges because they can act as fuel for wild fires and habitat for pests, such as mosquitoes [3]. Positive methods for dealing with waste tires benefitthe environment, as well as the economy and the community. Two possible methods for disposing waste tire are recycling and repurposing. Since 2003, approximately 80% of scrap tires have been recycled or repurposed annually [4]. One of the most common methods is to reuse scrap tires as a heat source ways that scrap tires are reused is as a heat source. In civil engineering, waste tires are used in stabilizing embankments and as asphalt component. Thousands of projects around the world have shown the success of the latter. Several studies have examined the performance of asphalt mixtures that use CR sourced from waste tires. These studies found that modified hot asphalt mixtures have excellent structures and increase the life span of a road surface, while decreasing maintenance costs, reflective cracking, and noise levels [3, 4]. Despite its many benefits, hot asphalt mixtures that contain crumb from waste tires are rarely used in Malaysia. Perhaps because of the lack of studiesthat highlights its benefits in Malaysian context.Previous research has shown that crumb rubber modifier (CRM) improve the performance of asphalt binders in its response to high temperatures, vulnerability to permanent deformation, and resistance to reflective cracking [5, 6]. The ability of conventional asphalts to handle increased stress decreases as traffic loads increase. New rubber modified asphalts are more capable of meeting increasing traffic requirements [7]. CRM asphalt binders are also an ecological method for dealing with scrap tires [8].CRhas been produced from scrap tires for over three decades [9].The steel fiber is removed during the grinding process using magnetic and air gravity systems. An ambient or a cryogenic process hen grinds the remaining rubber. In an ambient process, the tires remain at an ambient temperature. Knives attached to a rotor shred the tires. Screens sort the various gradations of the CR according to the size of the particles. The CR produced using an ambient process will have a rougher surface. In a cryogenic process, the rubber obtained from scrap tires is subjected to liquid nitrogen. The tires are crushed after being frozen [10]. The CR produced using a cryogenic process will have a smooth surface. The bindersfabricated using cryogenic CR also less viscous [10, 11].CR is typically processed using a dry or wet process. Some aggregates are replaced with CR in the dry process. The final productis often referred to as rubber modified asphalt concrete mixtures, wherein the amount, size and gradation of CRM can vary. Robertsetal. [12]recommend the weight of CRM at 3% to 5% of the weight of the aggregate. Other sources suggest using asmaller amount (1% to 3%) in asphalt concrete mixtures [13]. When a wet process is used, the final product is referred to as asphalt rubber or rubberized asphalt. In both processes, the asphalt binder is modified using CRM before adding the aggregate.

■2.0 MATERIALS AND METHODS

2.1 Materials Properties And Sample Preparations

Hot asphalt mixtures were prepared according to JKR/SPJ/rev2005 [14].Asphaltic concrete 14 (AC14) was used as aggregate gradation. All mixes consisted of one conventional mixture and three mixtures with different sizes of CR (1 CR content, 2% of total aggregate weight). The dry process technique was used, wherein CR was added to the aggregate before adding the asphalt cement. The sizes of the CR used are as follows: size A (0.15mm), size B (0.425mm) and size C (1.18mm). The modified hot asphalt mixtures were compared with the conventional asphalt mixture. The aggregates were divided into batches according to the percentage passing on each size. Figure 1 shows the AC14 gradation analysis graph.

2.2 Resilient Modulus Test

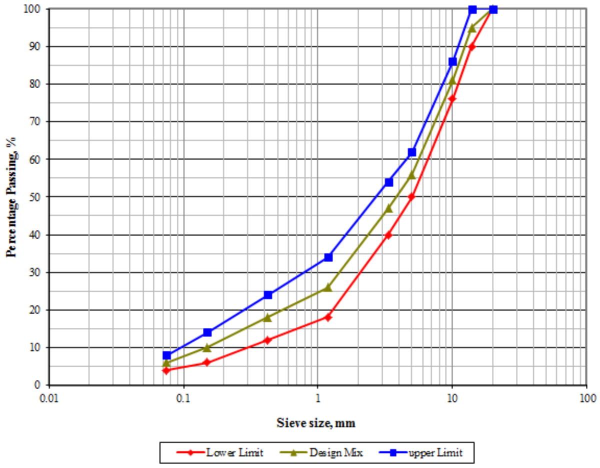


Figure 1 Aggregate gradation used in this investigation

Universal Testing Machine was used for the resilient modulus test according toASTM D4123standard [15].The test was conducted at 25°C and 40°C (±1°C). A peak load of 1000N was applied along the vertical diameter of specimen. The resulting horizontal deformation was measured. Assumed Poisson's ratio was used to calculate a resilient modulus. Figure 2 shows the resilient modulus test apparatus.

Figure 2 Universal testing machine (left) andarrangement sample for resilient modulus test (right)

2.3 Indirect Tensile Strength Test (ITS)

Marshall Design Method was used to prepare the samples for ITS, which was conducted according to ASTM D6931 standard [16].Specimens were left to cool in a controlled temperature cabinet at 25°C for at least 3 hours. The specimens were then tested in a Marshall machine for ITS at 50.8 mm /min until recording the ultimate load resistance was recorded. Figure 3 shows the arrangement of the equipment for ITS. The following equation was used for calculating the ITS.

$$ITS = (2 \times P \times G) / (\pi \times D \times H) \qquad (1)$$

WhereP is Ultimate applied load required to fail specimen (Kg); G is Gravitational force (9.806 m/sec²); H is Height of specimen (mm); and D is Diameter of specimen (mm).

Figure 3 Indirect tensile strength test equipment used through the study

2.4 Stability Test

Stability test is conducted to determine the stability of the Marshall specimen according to ASTM D6927 standard [17]. The specimens were prepared by Marshall Design Method and then submerged in a water bath at 60°C for about 45minutes. The specimens were then loaded into a Marshall Stability Machine at a constant rate of deformation of 50.8 mm/min until the maximum load was reached. The duration for removing specimen from water bath did not exceeded 30 seconds. Figure 4 shows the apparatus for stability test. The stability was calculated by the following equation:

$$Stability = 2.326 \times P \times g \times e \qquad (2)$$

Where P is Maximum Stability Load (Kg); G is Gravitational Force (9.806 m/sec^2); and C is Correction Factor.

Figure 4 Stability test apparatus used this investigation

2.5 Dynamic Creep Test

The dynamic creep test is the simplest method of assessing resistance to permanent deformation or rutting. The specimen used in the test had dimensions similar to the specimen used for resilient modulus test. The dynamic creep test was conducted according to the Texas Department of Transportation Standard

Test Designation Tex-231-F [18]. Specimens were placed in a controlled temperature chamber maintained at test temperature40°C for 3 to 5 hours prior to the start of the test. The specimen is placed in the machine and subjected to 3600 cyclic loads with applied axial stress of 300kPa, which takes about 40minutes to complete for each specimen. Figure 5 shows the arrangement for the dynamic creep test.The latter was determined from the following equation:

$$\text{Stiffness Modulus} = \text{Applied Axial Stress} / (\varepsilon@\,3600 - \varepsilon@\,2000) \qquad (3)$$

Where ε@3600 is strain at 3600 cycle obtained from creep curve; and ε @ 2000 is strain at 2000 cycle obtained from creep curve

Figure 5 Dynamic creep test equipment used in this study

3.0 RESULTS AND DISCUSSIONS

The results of laboratory works were given in this section to investigate the influences of crumb rubber sizes on hot mix asphalt mixtures. The specimens prepared based onoptimum bitumen content (OBC) from the Marshall test.

3.1 Effect Of CR Size On Mix Design Parameters

Optimum bitumen content for each mix type was determined by plotting several graphs that include density, stability, voids in mix (VIM) and voidsfilled with bitumen (VFB) versus bitumen content. Theaverage wascalculated todetermine the OBC for each mix. Other volumetric properties were determined for each mix type based on the calculated of OBC.

Table 1 Marshall Results for Conventional and Modified Mixes

Volumetric Properties	Mix Type				
	Control Mix	Size A 0.15mm	Size B 0.425mm	Size C 1.18mm	Specification (JKR/SPJ/rev/2008)
OBC (%)	5.3	5.6	5.55	5.5	4.0-6.0
Density	2.329	2.206	2.258	2.323	-
Stability (Kg)	1290	1090	1080	962	> 815
Flow (mm)	3.15	2.90	2.95	5.1	2.0-4.0
Stiffness (Kg/mm)	430	342	335	196	> 203
VTM (%)	4.2	3.0	3.0	3.6	3-5
VFA (%)	80	67	70	80	70-80

Table 1show that OBC increased when CR was added to the mix. Such behavior could be attributed to the absorption of bitumen by the CR, which reduced its viscosity and increased the OBC. OBC decreased as CR size increased because the surface area of CR decreased. Thus,less bitumen is absorbed by the CR which results in decreased OBC [19]. Theaddition of rubberreduced the stiffness and stability of the mixture, whereas decreased CR size increased the said stiffness and stability. This finding may be attributed to elastic behavior of the CR. The specific gravity of the compacted samples shows the same trends that caused droppingin specific gravity when CR is used, but its value decreased when CR size decreased. VTM and VFB showed opposite results. Overall, the different CR sizes used in the present study indicate that most of the volumetric properties met JKR specifications. The stability and flow values for size C modified asphalt were not within acceptable ranges. TheVFA of size A modified asphalt was also outside the range.Size B modified asphalt demonstrated the best results among all modified mixes. Mixes with elastic behavior allow asphalt mixes to recover from deformation under repeated loading [20].

3.2 Effect Of CR Size On Resilient Modulus

The resilient modulus measured in indirect tensile mode effectively represents the elastic properties of asphalt mixtures under repeated load. Figure 6 and 7 show the mean resilience for each mix typefor both test temperatures.The figures show thatthe resilient modulus significantly decreases as the temperature increases, regardless of rubber size. Furthermore, the addition of CR reduced the resilient modulus. Increasing CR size reduced the resilient modulus of the modified asphalt mixtures.Finally, it can be concluded that size A CR exhibited the best results.

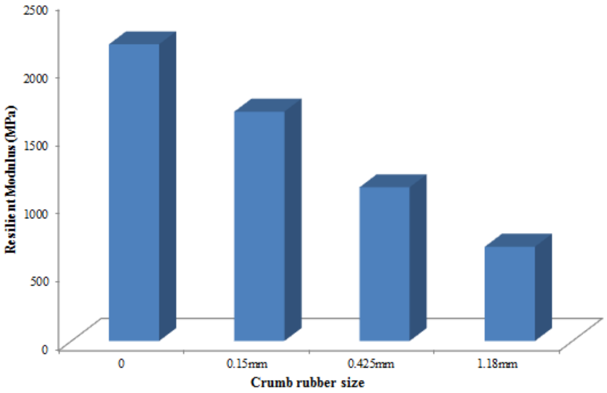


Figure 6 Resilient modulus at temperature25°C

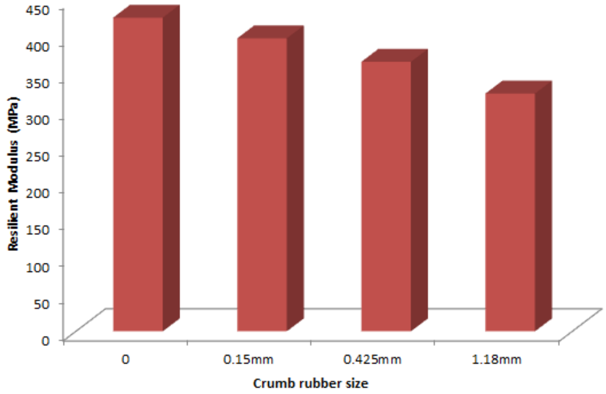


Figure 7 Resilient modulus at temperature 40°C

3.3 Effect of CR Size On ITS

ITS test was performed on all mixes. Figure 8 shows the test results. Each result represents the average of the three specimens tested for each condition. CR caused a slight reduction in mix cohesion (Figure 8). The addition of CR lowered the ITS of modified mixes compared with the conventional mix. This result indicates a loss of structural capacity in the rubber mixtures [21]. ITSdecreased slightly with increasing CR size possibly because of low cohesion, which can be attributed to a poor interaction between CR and bitumen. Thus, the ITS test was used because it directly measures tensile strengthandcalculates mix cohesion. The results show that the rubber modified mix with size A CR had the tensile strength value(305.88Kpa)compared with mixes size B and size C.

3.4 Effect Of CR Size On Stability

The stability test empirically measured the bearing capacity of mixes under traffic loads and their resistance to stresses and strains. Figure 9 shows the relationship between the stability value and the different rubber size mixes.A lower stability value occurred for modified asphalt size C. The stability value decreased with increasing CR size. The stability of asphalt mixtures depend on bitumen cohesion. Cohesion results from the bonding ability of bitumen and increases with bitumen content [22]. However, an extremely high stability value produces a stiff and less durable pavement mixture, which causes instability problem. Reduced stability with rubber addition is caused by the elastic properties of the rubber particles [23]. Thus, 0.15mm CR is the most stable because it gives the highest stability value compared to 0.425mm and 1.18mm, respectively.

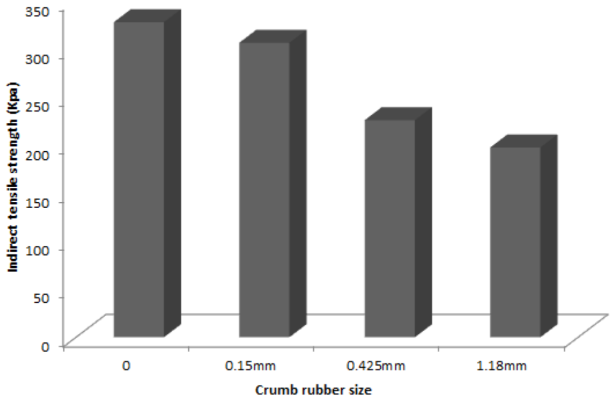


Figure 8 Indirect tensile strength results at different CR size

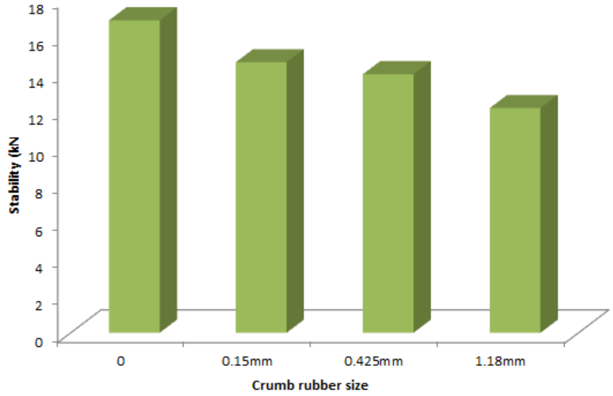


Figure 9 Stability of asphaltic concrete at different CR size

3.5 Effect OF Cr SIZE ON DYNAMIC CREEP

Dynamic creep test is used to determine the strength of material for resisting cyclic loads that are continuously applied for a long period of time. Repeated stress applicationsunder comparatively low mix stiffness conditions lead to the accumulation of permanent deformations at the pavement surface. The results of the creep test were represented in terms of permanent deformation and stiffness modulus. Figures 10 and 11present the relationship between the stiffness modulus value and permanent deformation with the different rubber sizes mixtures.

Figure 10 show that the addition of CR to the HMA plays a key role in reducing its permanent deformation. The effect of CR size can be observed: thesize A mixture showed better resistance to permanent deformation than others because of the greater elasticity offered by the rubber particles.Figure 11 indicates that the addition of CR significantly reduced the stiffness modulus of all CR sizes. Stiffness modulus also decreased when CR size increased. Size Ahas the highest stiffness modulus.

Generally, when CR is added to the mixture, the engineering properties of HMA such as resilient modulus, ITS, stability and stiffness modulus are significantly reduced. This effect could be attributed to the reduced cohesion of the mix and adhesion problems between the CR and the binder, which can affect the blending of the aggregate and CR. This mechanism results a non-homogeneous mix that will decrease engineering properties. A biggest CR results in weaker engineering properties. The stronger matrix was formed by homogenously mixing smaller rubber particlesand maintaining better adhesion between bitumen andaggregates as a result of uniform mixing and distribution [24]. Finer CRs tend to absorb more oil fraction from bitumen because of the increase in surface area.

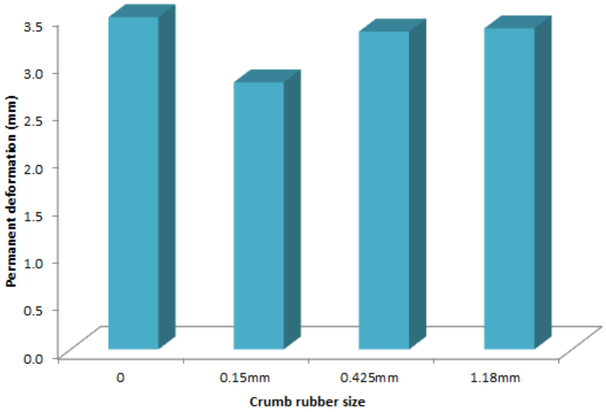


Figure 10 Permanent deformation of asphaltic concrete at varying CR size

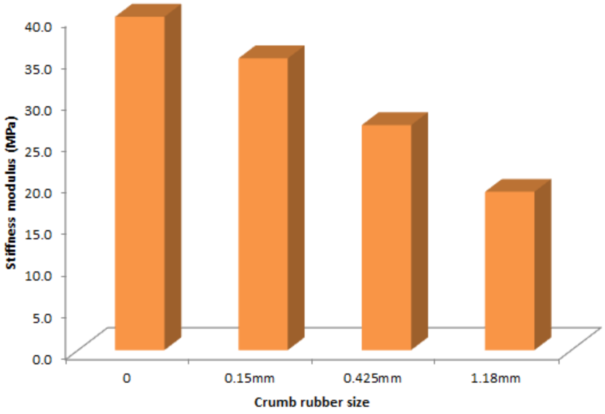


Figure 11 Stiffness modulus of asphaltic concrete at varying CR

■4.0 CONCLUSION

The different CR sizes added to HMA had noticeably different effects on the performance of modified mixtures.

a. The addition of rubber mainly influenced the characteristics of asphalt rubber and produce better performance. The best modified asphalt mixture laboratorial behavior was obtained for the mixture with the most modified binder, which had smaller CR particle sizes. Modified asphalt size A (0.15mm) was the best performing HMA. Larger particles did not seem to cause damage, as shown in other cases.
b. OBC value increased when CR is added to the HMA mixtures. OBC values also increase as CR size decreased in the same rubber content.
c. The Marshall properties obtained showed that stability greatly decreased when CR was added or when CR size was increased. Density also increased by increasing CR size. Other volumetric properties, such as VTM and VFB, also slightly increased as CR size increased.
d. Optimum CR size was determined based on the volumetric properties of the Marshall test. Size B presented the best results because all volumetric property values fell within the acceptable range according to JKR Specification.
e. Adding CR decreases resilient modulus values compared with the conventional mix. Increasing rubber size decreased the resilient modulus for the same rubber content.
f. Incorporating CR recycled from ground tires to conventional binders reduced the ITS of the asphalt-rubber specimens. ITS decreased when CR size was increased.
g. Stability decreased as CR size increased.
h. The addition of CR decreased permanent deformation and stiffness modulus. Permanent deformation values increased and stiffness modulus values decreased as CR size increased.

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